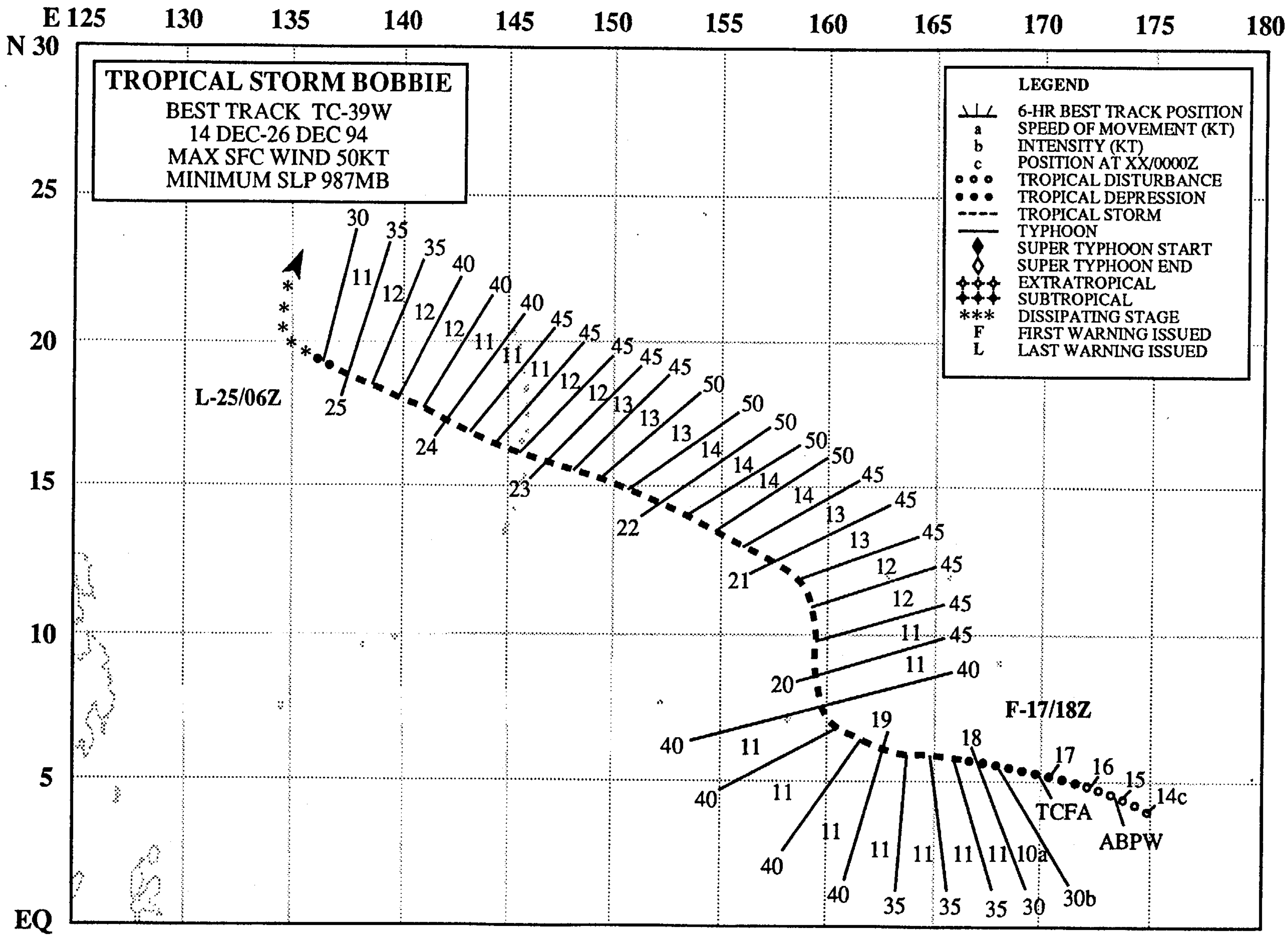
TROPICAL STORM BOBBIE
BEST TRACK TC-39W
14 DEC-26 DEC 94
MAX SFC WIND 50KT
MINIMUM SLP 987MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 125
130
135
140
145
150
155
160
165
170
175
180
N 30
25
20
15
10
5
EQ
L-25/06Z
F-17/18Z
TCFA
ABPW
14c
10a
30b

TROPICAL STORM BOBBIE (39W)

I. HIGHLIGHTS

Bobbie was the last significant tropical cyclone of 1994 in the western North Pacific. For its entire life, it was a sheared system with the low-level circulation center displaced from the deep convection. Its low-level circulation center was often obscured beneath cirrus debris. The cirrus shield over its deep convection lacked the typical characteristics produced by shear. SSM/I imagery from the DMSP satellites, and scatterometer-derived winds from the ERS-1 satellite (in conjunction with conventional IR and visible imagery) were instrumental in determining the location and structure of Bobbie.

II. TRACK AND INTENSITY

During mid-December 1994, the large-scale low-level wind pattern of the deep tropics of the western North Pacific featured equatorial westerlies bounded by near-equatorial troughs at roughly 5°N and 5°S. The equatorial westerlies and associated large-scale deep convection extended eastward beyond the international date line. This flow pattern occurs frequently during the Spring and late Fall, and has been defined as the "twin trough" pattern (see Figure 3-39-1). Most episodes of twin tropical cyclones occur in association with this large-scale low-level wind pattern. On 15 December, an area of persistent convection associated with a broad, weak surface circulation in the Marshall Islands was mentioned in the 150600Z December Significant Tropical Weather Advisory. At 170430, a Tropical Cyclone Formation Alert was issued. It stated, in part:

"... a pre-existing [low-level] circulation with persistent convection [is intensifying]. ... surface pressures [have dropped] in the vicinity of Majuro. Their synoptic observation from 170300Z showed [the] surface pressure at 1002.7 mb ... this system is elongated east-west and may have several circulation centers."

Based on further synoptic data from the Marshall Islands, a tropical depression warning was issued at 171800Z. Remarks contained on this warning included:

"... this system is poorly organized at the present time, but is showing signs of steady development. The minimum central pressure in the broad low pressure region is estimated to be 1002 mb. If the [JTWC] anticipates that this tropical depression will reach tropical storm intensity, then a standard 72-hour tropical cyclone warning will be issued ..."

At 181800, JTWC forecasters predicted that the the tropical depression would become a tropical storm in 24 hours, so a standard 72-hour tropical cyclone warning was issued. Remarks on this warning stated:

" ... synoptic data from Micronesia

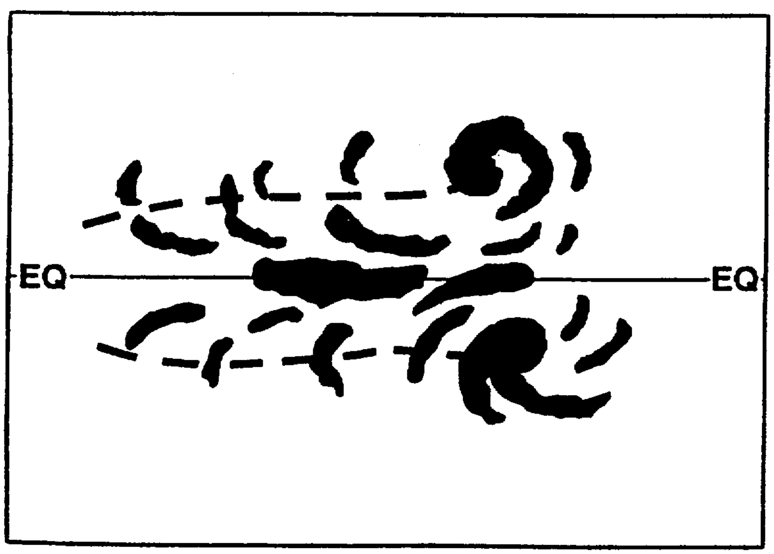

Figure 3-39-1 Schematic illustration of the distribution of deep convection associated with the "twin-trough" pattern. The axes of the near-equatorial troughs are represented by dashed lines.

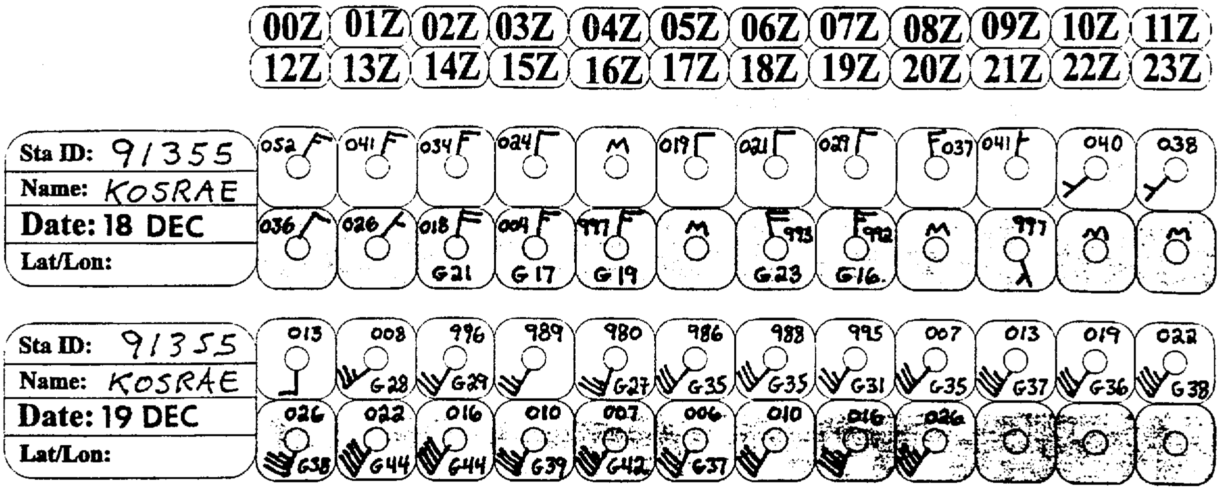

Figure 3-39-2 Time series of hourly synoptic observations at Kosrae (WMO 91355) as Bobbie passed near the island from east to west.

indicate that Tropical Depression 39W is steadily deepening over a large area. Near-gale force winds are present north of the broad low pressure center. . . . [the] warning position is based on the estimated position of the low pressure center from synoptic data; satellite imagery does not reveal a single, well-defined cyclone center and is considered to be unreliable at the present time. . . . "

This disturbance had the characteristics of a monsoon depression (JTWC 1993): a large (1500 km diameter) region of cyclonic wind flow, a relatively large (200 km diameter) light wind core, and a lack of persistent central convection. At 190000Z, the system was upgraded to Tropical Storm Bobbie based upon visible satellite imagery and synoptic reports from Kosrae (WMO 91355) and Pingelap (91352). Synoptic data from Kosrae (Figure 3-39-2) indicated that a band of 40 kt (21 m/sec) southwesterly wind existed in the southeastern quadrant of Bobbie.

At 191200Z, Bobbie turned toward the north for 24 hours and then, at 201200Z, resumed a west-northwesward track. Bobbie intensified very slowly and reached its peak intensity of 50 kt (26 m/sec) at 220000Z. Between 230000Z and 230600Z, the broad low-level center of Bobbie passed 60 nm (110 km) to the north of Saipan. Bobbie continued on a west-northwestward track until 251800Z when its remnant low-level circulation turned north and recurved.

III. DISCUSSION

In its simplest form, the deep convection associated with a "shear"-type tropical cyclone is displaced down-shear of the low-level circulation center (LLCC). The cirrus emanating from the top of this deep convection is carried farther down-shear leaving the LLCC exposed (i.e., not obscured by deep convection or by cirrus debris) (Figure 3-39-3). In such cases, the diagnosis of the position and intensity is relatively easy, especially during the daylight hours when the LLCC is easily detected in visible satellite imagery. The intensity is estimated based upon the tightness of curvature of the low-level cloud lines (Dvorak 1975) and by the separation distance of the LLCC from the edge of the cirrus canopy over the deep convection. On IR imagery, the intensity is estimated from the separation distance of the LLCC

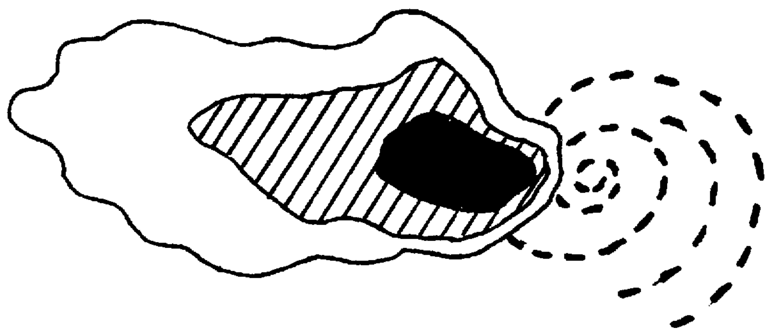

Figure 3-39-3 Schematic illustration of the structure of a typical sheared tropical cyclone. Black-shaded region shows coldest cloud top temperature. Dashed lines show low-level cloud lines. Vertical shear from the east has sharpened the temperature gradient on the eastern side of the deep convection, and has caused the low-level circulation center to become exposed on the eastern side of the deep convection.

from the edge of dense cirrus with a threshold equivalent black-body temperature of -42°C (Dvorak 1984). The highest intensity that can be diagnosed for a developing TC with a "shear" type cloud pattern is 55 kt (28 m/sec).

At intensities greater than 55 kt (28 m/sec), the LLCC tends to be under the dense cirrus canopy, or surrounded by spiral bands of deep convection. As soon as the LLCC is deemed to have moved under the cirrus canopy, the pattern type changes to "central dense overcast" (CDO). On visible satellite imagery, the intensity of a tropical cyclone with a CDO cloud pattern is determined primarily by the diameter of the CDO. On IR imagery, it is determined by the estimated embedded distance of the LLCC under the cold cirrus cloud canopy.

On some occasions, the LLCC of a tropical cyclone that possesses a "shear" type cloud pattern is often difficult to locate with conventional visible and IR imagery. Cirrus debris may obscure the low-level cloud lines. This is especially true at night when only IR imagery is available, and thin cirrus, which may not obstruct the view of the low-level cloud lines in visible imagery, is completely obstuctive to the view of low-level features. The nighttime difficulty of tracking an exposed LLCC has led to the common diagnostic error that has come to be known as the "sunrise surprise". This occurs when the analyst estimates the postion of the LLCC too close to the deep convection at night, only to find it displaced a larger distance from it on the first visible image of morning.

Even in the abscence of distinct low-level cloud lines marking the LLCC of a "shear" type tropical cyclone, the postion of the LLCC may be estimated (with less confidence) by other manifestations of shear in the deep convection. Under shearing conditions, the up-shear side of the cold-cloud canopy usually has a sharp edge (Figure 3-39-3), and the down-shear side the cirrus thins more gradually. On enhanced IR (EIR) imagery, sharp temperature gradients are found on the up-shear side of the cirrus cloud shield and much less steep gradients of temperature are found down-shear (Figure 3-39-3). For diagnostic purposes, it is best to position the LLCC on the up-shear edge of the cloud at a separation distance consistent with earlier visible imagery, and consistent with the past motion and expected changes of intensity.

For much of its life, Bobbie's cirrus outflow exhibited no appearent manifistation of shear. Its cirrus canopy and cirrus outflow were symmetrical with respect to the cloud system center (CSC). The persistent convection on the western side of the LLCC — at first showing conventional manifestations of shear (i.e., an easily detected LLCC east of the deep convection and cirrus outflow streaming westward from this deep convection) — became symmetrical in appearance (Figure 3-39-4). In addition to the

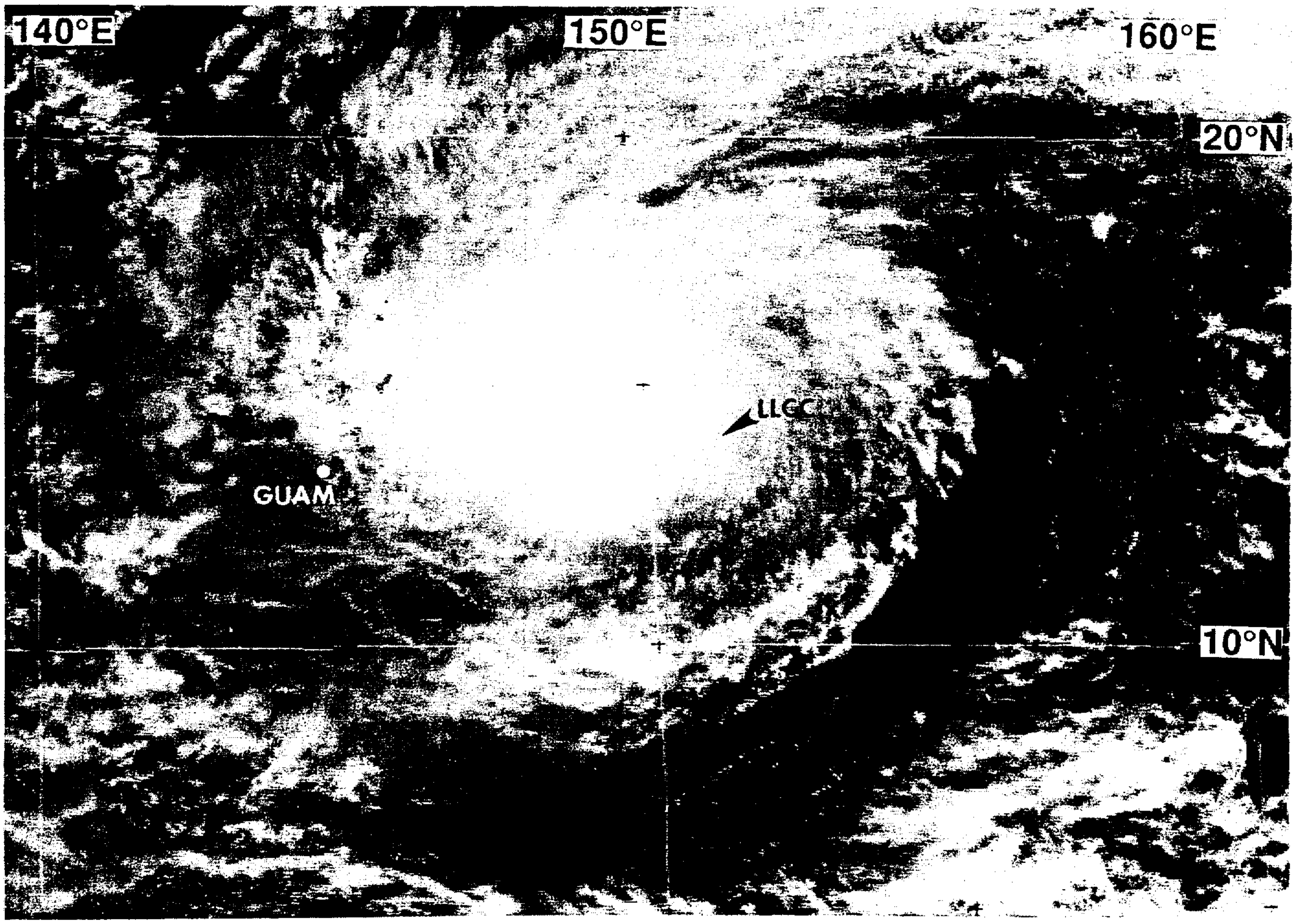

Figure 3-39-4 Bobbie at its peak intensity of 50 kt (26 m/sec). The low-level circulation center (labeled "LLCC") is displaced about 120 nm to the southeast of the center of the deep convection (220031Z December visible GMS imagery).

symmetry of the cloud shield, the LLCC was obscured by cirrus debris. At the time of the imagery in Figure 3-39-4, the LLCC was difficult to locate. Satellite analysts at the JTWC considered the option of locating the LLCC closer to the CSC, thereby increasing the intensity estimate of Bobbie to the typhoon threshold. However, the rapid motion resulting from such a placement, and the constraint of prior knowledge of the sheared structure of the system were factored into the decision to position the LLCC east of the CSC and thereby hold the intensity estimate below the typhoon threshold. Wind vectors obtained from the scatterometer aboard the ERS-1 satellite (Figure 3-31-5) later confirmed the large displacement of the LLCC from the CSC at the time of the satellite image in Figure 3-39-4.

A day later, the large displacement of the LLCC of Bobbie to the east-southeast of the CSC was confirmed by visible satellite imagery (Figure 3-39-6a) and by microwave imagery (Figure 3-39-b) obtained from a DMSP satellite. Conventional unenhanced IR imagery (Figure 3-39-6d) and enhanced IR imagery (Figure 3-39-6e) gave little indication of the large displacement of the LLCC from the CSC. Microwave images of Bobbie (Figures 3-39-6b,c) clearly depict the structure of the system: the roots of the deep convection responsible for the large oval-shaped cirrus cloud canopy seen in the visible and IR imagery (Figure 3-39-6a,d,e) are to the west of the LLCC along a major spiral band leading into a well-defined LLCC. Additional confirmation of the large (120 nm ; 220 km) displacement of the LLCC of

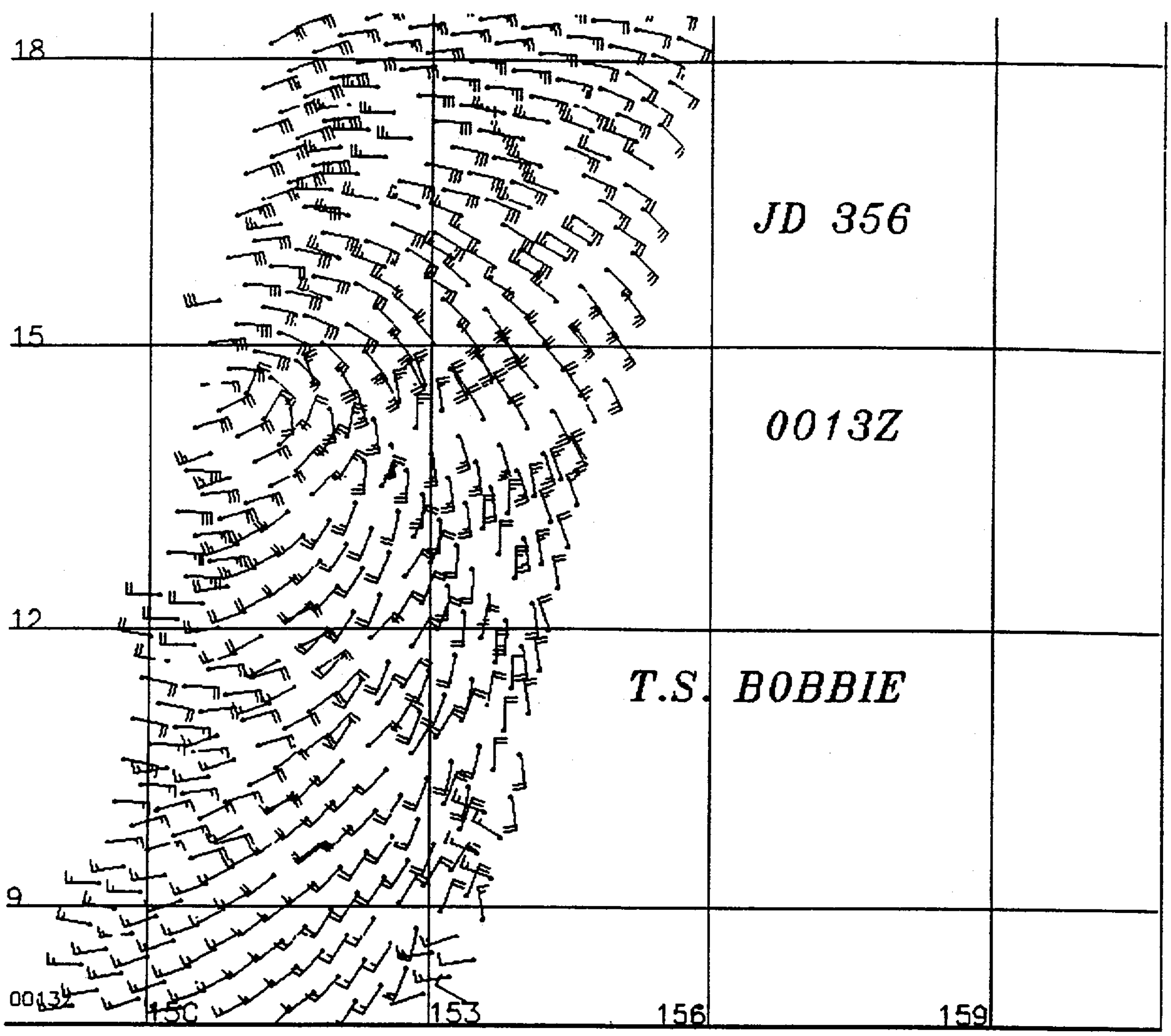

Figure 3-39-5 Wind vectors derived from the scatterometer aboard the ERS-1 satellite clearly indicate the location of Bobbie's low-level circulation center. Maximum wind vector is 35 kt (17 m/sec) on the north side of the circulation center. The timing of this pass (220013Z December) is nearly coincident with the visible image in Figure 3-39-4.

Bobbie from its CSC was obtained from synoptic reports in the Mariana Islands during Bobbie's passage through that region.

To summarize, the structure of Bobbie was difficult to diagnose for a large portion of its track, especially as it neared and passed through the Mariana island chain. Despite the presence of a persistent, large, oval-shaped dense cirrus canopy (which could have been diagnosed as the CDO of the system), a very careful study of visible satellite imagery, coupled with valuable additional information from microwave imagery and scatterometer winds indicated that the LLCC of Bobbie was well-displaced from the CSC (Figures 3-39-7). The total suite of multi-spectral information (visible, IR, active and passive microwave, and radar reflectivity) from numerous remote sensing platforms (i.e., the GMS, NOAA, DMSP, and ERS-1satellites; and, Guam's NEXRAD), was absolutely essential to accurately locating the LLCC of Bobbie, and reasonably diagnosing its intensity.

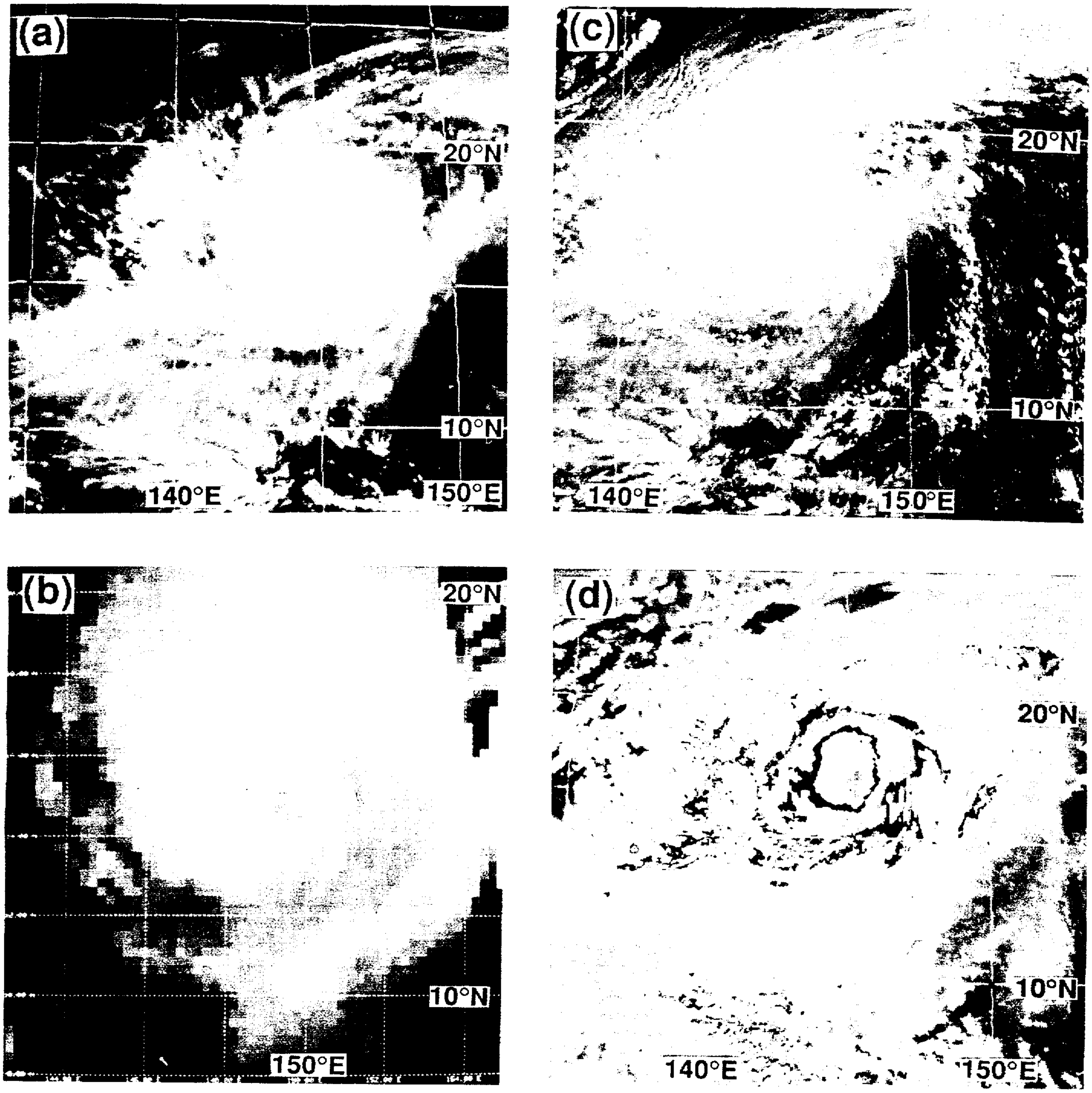

Figure 3-39-6 (a) Cirrus outflow from Bobbie's deep convection appears to be nearly symmetrical (230031Z December infrared GMS imagery). (b) Bobbie's deep convection is seen to be located on a major spiral band which wraps into a well-defined low-level circulation center (230014Z December DMSP 85H microwave imagery). (c)The low-level circulation center of Bobbie is relatively easy to locate beneath thin cirrus to the east-southeast of the deep convection (230031Z December GMS visible imagery). (d) Enhancing the IR imagery in (a) fails to reveal any of the traditional manifestations of vertical shear (230031Z December enhanced infrared GMS imagery).

IV. IMPACT

Bobbie brought heavy rain and gales to some islands and atolls in Micronesia. No reports of injuries or significant damage were received.

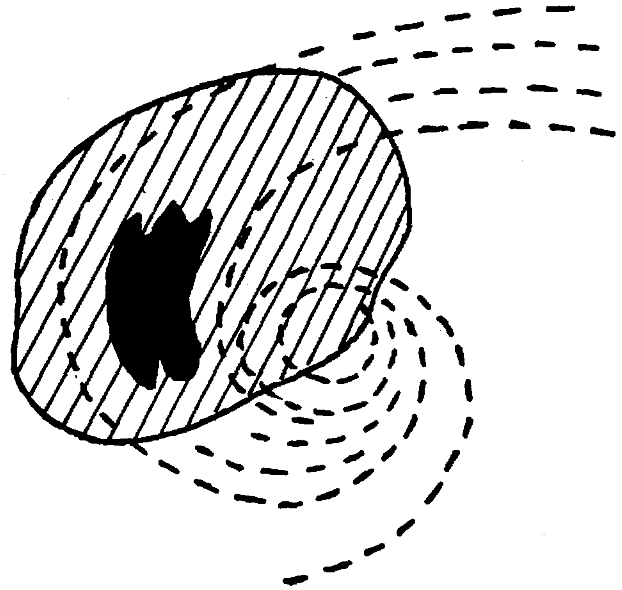

Figure 3-39-7 Schematic illustration of the structure of Bobbie as it passed through the Mariana island chain. Deep convection (black-shaded region) is located well to the west-northwest of the low-level circulation center, and is producing a large nearly symmetrical cirrus canopy (hatched region). The symmetry of the cirrus canopy, and its blocking of the view of the low-level circulation center, made diagnosis of the position and intensity of Bobbie relatively difficult. Microwave imagery and scatterometer-derived winds were valuable in defining the structure of Bobbie.